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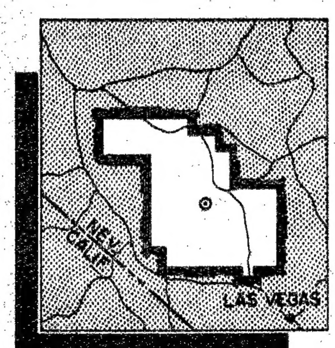
Operation TUMBLER-SNAPPER

NEVADA PROVING GROUNDS

April-June, 1952

Project 7.2

DETECTION OF AIRBORNE LOW-FREQUENCY SOUND FROM ATOMIC EXPLOSIONS



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OPERATION TUMBLER-SNAPPER

Project 7.2

DETECTION OF AIRBORNE LOW-FREQUENCY SOUND FROM ATOMIC EXPLOSIONS

REPORT TO THE TEST DIRECTOR

by

G. B. Olmsted

15 September 1952

Headquarters, U. S. Air Force
Office for Atomic Energy, DCS/O
AFOAT-1

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ABSTRACT

Measurements of the airborne low-frequency sound from the atomic explosions of Operation TUMBLER-SNAPPER (April, May, and June, 1952) were made at seven remote locations covering a variety of directions and distances from the Nevada Proving Grounds in order to establish the range and accuracy of location of acoustic long-range detection equipment. All shots except the first two were detected at least to 3700 kilometers from the test site. Results for Shot 1 were negative but the closest station for this test was at 3400 kilometers. Shot 2 was detected at 1300 km but not at 2500 km. A shift in preferred direction of transmission was noted with westward propagation preferred after the middle of May. Data are consistent with expected seasonal changes in east-west winds in the stratosphere. Continued acoustic measurements during subsequent atomic tests are recommended.

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PREFACE

The purpose of this report is to summarize and correlate all results from remote acoustic measurements during Operation TUMBLER-SNAPPER. Conclusions and recommendations in this report are those of Headquarters U.S. Air Force, AFOAT-1, and are not necessarily the views of agencies participating in the measurements and analyses.

ACKNOWLEDGMENTS

The data presented in this report were the result of work by the Signal Corps and by the National Bureau of Standards. Credit is due to all participating personnel listed below.

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The Special Projects Section of the U.S. Weather Bureau supplied meteorological data and analyses.

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ILLUSTRATIONS

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DETECTION OF AIRBORNE LOW-FREQUENCY SOUND FROM THE ATOMIC EXPLOSIONS OF OPERATION TUMBLER-SNAPPER

1.0 OBJECTIVE

Project 7.2 was a part of the continuing program to determine the reliability of acoustic long-range detection methods and to obtain data on explosions of known characteristics in order that signals received during routine operations of the Atomic Energy Detection System can be better evaluated. Results from TUMBLER-SNAPPER supplement past data from GREENHOUSE and BUSTER-JANGLE concerning maximum detection range and accuracy of source location for various types of acoustic equipment under a variety of conditions. TUMBLER-SNAPPER was particularly interesting because it afforded an opportunity to observe the changes in acoustic propagation coincident with the change from spring to summer conditions in the upper atmosphere.

2.0 HISTORICAL BACKGROUND

The first systematic effort to detect at very great distances the airborne pressure wave from an atomic explosion was made by the Signal Corps Engineering Laboratories[1] and by the Naval Ordnance Laboratory[2] during Operation CROSSROADS, July, 1946. Results at distances greater than 350 kilometers were either negative or controversial for Test Able and definitely negative for Test Baker.

During Operation SANDSTONE, April and May, 1948, a comprehensive network of acoustic stations out to 1900 kilometers supplemented by a sparse network out to 4500 kilometers resulted in positive detection at 1100 km but not at 1900 km for Test Xray and at 1900 km but not at 3500 km for Tests Yoke and Zebra. Measurements were made by the Signal Corps Engineering Laboratories, the Navy Electronics Laboratory, the Naval Ordnance Laboratory, and the Air Force Watson Laboratories under the sponsorship of Headquarters USAF, AFOAT-1[3].

---

[1] Tab D to Volume VI, "Report of Operation FITZWILLIAM", Evans Signal Laboratory, Project BIRTHROOT (1949) (SECRET - SECURITY INFORMATION)

[2] CROSSROADS Technical Instrumentation Report, "Remote Microbarometric Measurements (Inductiphone, Kwajalein; Washington, D.C.) Project No. II-28, Naval Ordnance Laboratory (SECRET, RESTRICTED DATA)

[3] Volume VI, Report of Operation FITZWILLIAM, "Acoustic and Seismic Detection", U.S. Air Force (SECRET - SECURITY INFORMATION)

[redacted]

During Operation GREENHOUSE, April and May, 1951, 12 experimental acoustic stations were established at fairly uniform intervals of distance out to 4500 kilometers, six to the east and six to the west of the Eniwetok Test Site. The work was accomplished through the co-operative effort of the Signal Corps Engineering Laboratories[1], the Navy Electronics Laboratory[2], the Naval Ordnance Laboratory[3], and the National Bureau of Standards[4], under the sponsorship of AFOAT-1. The equipment used for GREENHOUSE was considerably more sensitive than that used for SANDSTONE. In addition, elaborate noise-reducing techniques considerably improved the chances of detection. Every GREENHOUSE atomic explosion was detected at a range of 4500 kilometers. Minor directional effects in propagation were observed.

Operation BUSTER-JANGLE, October and November, 1951, afforded the first opportunity to study very long-range acoustic propagation from atomic bombs detonated in continental U.S.A. Through the cooperative effort of the Signal Corps Engineering Laboratories, the Navy Electronics Laboratory and the National Bureau of Standards, 10 special acoustic stations were established and operated at a variety of distances and azimuths from the Nevada Proving Grounds[5]. Every atomic explosion except the JANGLE surface shot was detected at least to a range of 3600 kilometers. The surface shot was detected at 2800 km but not at 3400 km. Transmission toward the east was consistently better than toward the west.

3.0 INSTRUMENTATION

Each experimental acoustic station consisted of at least four microphones arranged to permit an accurate determination of the azimuth

---

1/ Final Report, "Signal Corps Portion, 7.2 Program, Operation GREENHOUSE", AFOAT-1 Project No. B/52, 15 February 1952, by Crenshaw, Lonnie, and Pressman, Signal Corps Engineering Laboratories. (SECRET - SECURITY INFORMATION)

2/ NEL Final Report B/53/A/ONR/NEL, "Airborne Low-Frequency Sound at Bikini, Kwajalein, and Guam from Atomic Explosions of Operation GREENHOUSE", 30 Sept 1951, by Hale, McLoughlin, and Pickens, Navy Electronics Laboratory. (SECRET - SECURITY INFORMATION)

3/ NAVORD Report 2153, "Report on Microbarometric Data Taken During Project GREENHOUSE", 17 August 1951, by Ellingson, Pomerantz, Opland, and Coate, Naval Ordnance Laboratory. (SECRET - SECURITY INFORMATION)

4/ NBS Report No. 1C104, dated 15 Sept 1952. (SECRET-SECURITY INFORMATION)

5/ Rpt No. WT-322, "Detection of Airborne Low-Frequency Sound from the Atomic Explosions of BUSTER and JANGLE", (SECRET-SECURITY INFORMATION)

[redacted]

and horizontal phase velocity of acoustic waves. A quadrilateral arrangement of microphones, approximately square, with 4 to 10 miles between microphones was used at all except the Washington, D.C. station. The microphone arrangement at Washington consisted of a 2½-mile triangle approximately centered inside a 14-mile triangle. Each microphone was equipped with a linear, pressure-averaging pipe array, ranging from 800 feet to 1740 feet in length. These arrays were designed by the Signal Corps to give a maximum reduction of noise due to atmospheric turbulence at an economical cost. Signals were transmitted over wire lines from microphone outposts to a recording center where each channel was recorded individually on Esterline-Angus Graphic Recording Milliammeters. In addition, signals were recorded on magnetic tape at all stations in the continental United States. Timing was accomplished by clocks and chronometers supplemented by radio checks with National Bureau of Standards Radio Station WWV.

Two types of equipment were used during the TUMBLER-SNAPPER tests: namely, Signal Corps Infrasonic Microphone System, M-2 Modified, at Signal Corps stations, and National Bureau of Standards Infrasonic Single-Microphone System at the NBS Station. There was no essential difference between the equipment used for BUSTER-JANGLE and that used for TUMBLER-SNAPPER. Equipment details may be obtained from the report on Operation BUSTER-JANGLE[1]. Each microphone system was capable of detecting a change in atmospheric pressure of a fraction of a dyne per square centimeter in the frequency range from one cycle per second to one cycle in 40 seconds.

Magnetic tape recording consisted of recording low-frequency signals directly on slowly moving tape (one-half inch per minute) in order that tapes could be played back at greatly increased speeds (7½ inches per second) and analyzed by audio techniques.

4.0 OPERATIONS

4.1 Participating Agencies

Project 7.2 was conducted jointly by the Signal Corps Engineering Laboratories and by the National Bureau of Standards under the sponsorship of Headquarters U.S. Air Force, AFOAT-1. The Signal Corps operated six stations and the Bureau one. The Office of the Chief Signal Officer (SIGGG-S) coordinated the Army effort.

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[1] Op. cit.

[redacted]

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TABLE 1

TUMBLER-SNAPPER Acoustic Station List

Station	Responsible Laboratory	Approx. Location N.Latitude	Approx. Location W.Longitude	Distance from Test Site (km)	Azimuth from Station to Test Site
Ft. Lewis, Wash.	SCEL1/	47°	122.5°	1230	152°
Pyote AFB, Tex.	SCEL	31°	103°	1350	300.7°
Breckinridge, Ky.	SCEL	38°	88°	2490	277.5°
Washington, D.C.	NBS2/	39°	77°	3400	279.0°
Belmar, N.J.	SCEL	40°	74°	3585	278.2°
Fairbanks, Alaska	SCEL	65°	148°	3710	130.5°
Oahu, T.H.	SCEL	21°	158°	4375	57.3°

1/ Signal Corps Engineering Laboratories

2/ National Bureau of Standards

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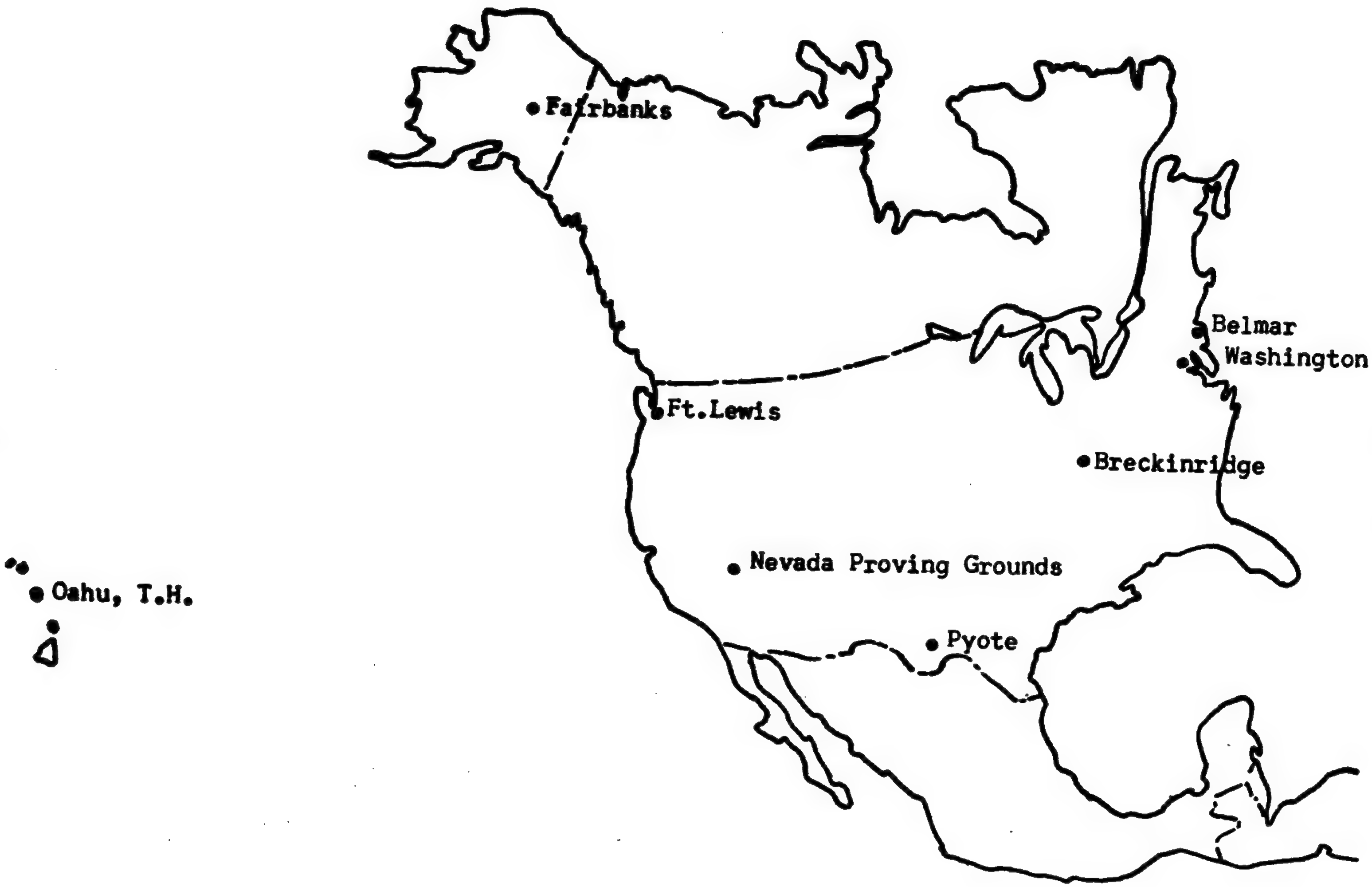

Fig. 1 Acoustic Stations for Operation TUMBLER-SNAPPER

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TABLE 2

Location and Time of Occurrence of TUMBLER-SNAPPER Atomic Detonations

Shot No.	Location		Time (GMT)			
	N. Latitude	W. Longitude	Date	Hrs	Min	Secs
1	36°47'35"	115°55'57"*	01 April	17	00	08
2	37°05'04.8"	116°01'11.0"*	15 April	17	29	57
3	37°05'04.8"	116°01'11.0"*	22 April	17	30	10
4	37°05'04.8"	116°01'11.0"*	01 May	16	29	59
5	37° 03'10.0"	116°06'09.2"	07 May	12	14	59
6	37°05'42.5"	116°06'10.8"	25 May	12	00	00
7	37°02'52.5"	116°01'14.2"	01 June	11	55	00
8	37°08'16.5"	116°07'06.1"	05 June	11	55	00

* Locations given are aiming points in the case of air drops.

4.2 Station List

Stations operated for Operation TUMBLER-SNAPPER, listed in Table 1, are shown in Figure 1. Stations at Ft. Lewis, Washington; Pyote AFB, Texas; and at Breckinridge, Kentucky, were not operational for the first atomic explosion since participation in TUMBLER had not been planned initially. All stations were operational for the remaining explosions in the series. Test times and locations are presented in Table 2.

5.0 RESULTS

Most of the results reported here were obtained from a visual analysis of the graphic records. It has not been possible to analyze an appreciable number of magnetic tape records as yet.

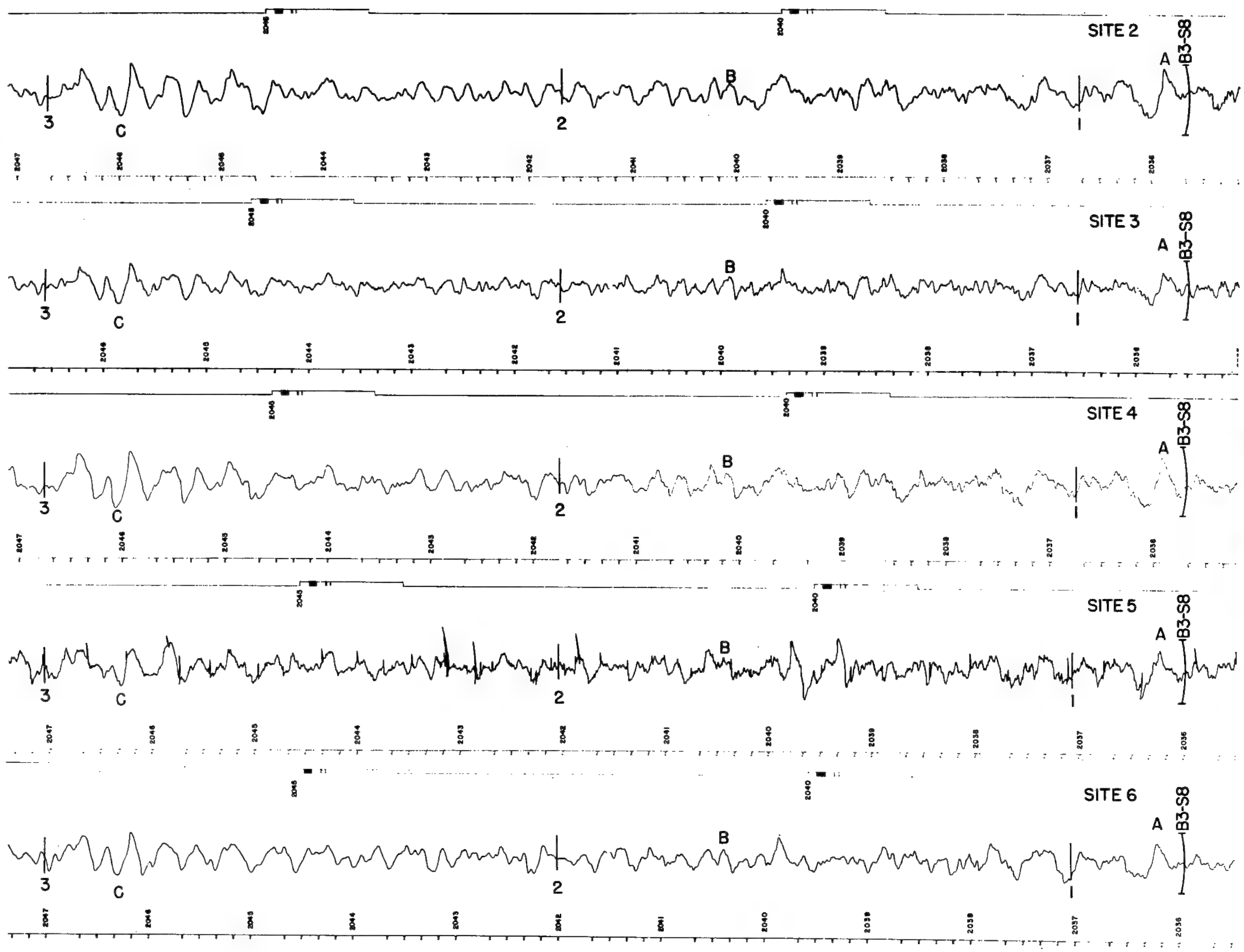

Fig. 2 Typical Graphic Record from Shot 3, 22 April 1952, at Washington, D.C.

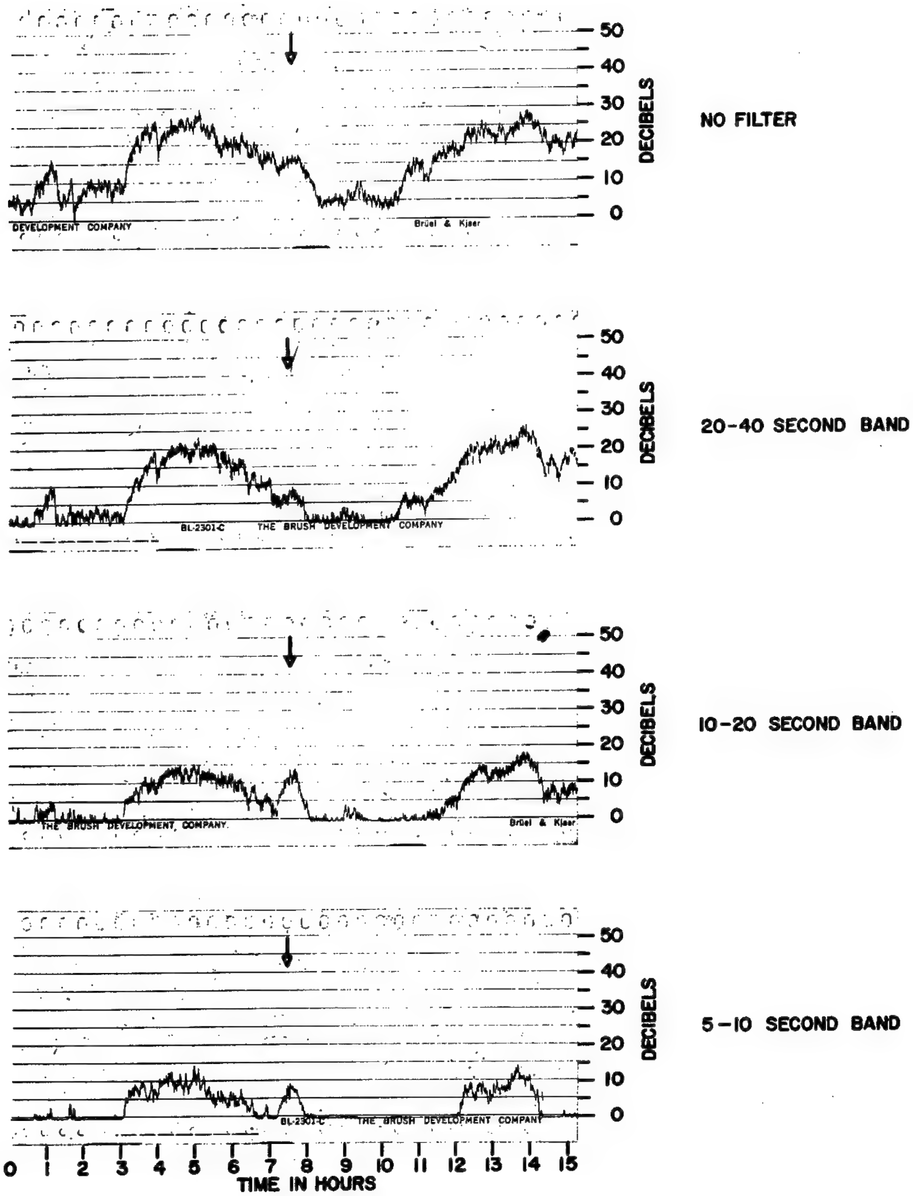

Fig. 3 High Speed Level Recorder Records of Magnetic Tape Data Passed Through Octave Filters, TUMBLER-SNAPPER Shot 3, 22 April 1952, at Washington, D. C.

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5.1 Analysis of Graphic Records

Basic acoustic data derived from visual analysis of pen-and-ink on paper records are presented in Tables 3 through 9. Included are: times of arrival of the first detectable signals and the maximum amplitude signals, durations of detectable signals, maximum zero-to-peak signal amplitudes, average zero-to-peak noise amplitudes, significant signal periods, average azimuths and ranges of horizontal phase velocities of incoming acoustic waves.

An early section of a typical, good graphic record is presented in Figure 2. The record size has been reduced by a factor of approximately six. The five traces are from the individual microphones in the Washington station. The fourth trace from the top shows a considerable amount of high-frequency electrical interference caused by a radio beacon located within a few feet of the local ac power supply to the microphone. Superposition of the various records with correct time lags shows the correlation between channels characteristic of a recording where the signal to noise ratio is good. Points A, B, and C mark corresponding phases on the five traces. Time in hours and minutes is marked along the edge of the traces. Equipment sensitivity is indicated by an arc at the right of each trace showing the deflection given by a pressure change of three dynes per square centimeter for signal frequencies in the pass-band of the microphone system.

The azimuth error for each acoustic arrival is given in Table 10. Azimuths are measured clockwise from true north. An "N" is used to show that the azimuth of the acoustic wave indicates a source to the north of the actual source, an "E" for acoustic wave east of actual source, etcetera.

The average speeds of travel of first detectable signals and of maximum amplitude signals are given in Tables 11 and 12. These speeds are computed by dividing the distance from source to station (measured along a great circle at the earth's surface) by the total elapsed time between the source time and the time of arrival at the station.

5.2 Analysis of Magnetic Tape Records

Results of a spectrum analysis on a single-channel of the magnetic tape recording at Washington, D.C., for Shot 3 are shown in Figure 3. The analysis was made by speeding up the tape recording during playback, filtering, and recording on a Bruel and Kjaer power level recorder. Power levels for the unfiltered signal and for various octave bands are given. Arrows indicate the signal from the bomb and remaining variations are noise. Decibel scales are employed. Time in hours is marked at the bottom of the figure.

[redacted]

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TABLE 3

Acoustic Data for TUMBLER-SNAPPER Shot 2
(Source Time: 15 April, 1730 GMT)

Station	GMT Time of Arrival First Hrs Min	GMT Time of Arrival Max. Hrs Min	Duration (Minutes)	Maximum Amplitude (dynes/cm^2) 0-Peak	Average Noise (dynes/cm^2) 0-Peak	Signal Period (Secs)	Azimuth	Horizontal Phase Velocity (meters/sec)
Ft. Lewis, Wash.	1840	1854	16	6.7	1.3	4-20	152.6°	304 - 380
Pyote AFB, Tex.	1841	1843	6	11.2	6.5	4-8	303.0°	315 - 344
Breckinridge, Ky.	Negative		-	-	7.3	-	-	-
Washington, D.C.	Negative		-	-	6.6	-	-	-
Belmar, N.J.	Negative		-	-	6.2	-	-	-
Fairbanks, Alaska	Negative		-	-	0.7	-	-	-
Oahu, T.H.	Negative		-	-	5.2	-	-	-

[redacted]

[redacted]

TABLE 4

Acoustic Data for TUMBLER-SNAPPER Shot 3
(Source Time: 22 April, 1730 GMT)

Station	GMT Time of Arrival First Hrs Min	GMT Time of Arrival Max. Hrs Min	Duration (Minutes)	Maximum Amplitude (dynes/cm^2) 0-Peak	Average Noise (dynes/cm^2) 0-Peak	Signal Period (Secs)	Azimuth	Horizontal Phase Velocity (meters/sec
Ft. Lewis, Wash.	1836	1839	26	29.6	3.0	5-18	150.6°	329-406
Pyote AFB, Tex.	1841	1844	23	16.9	1.9	10-25	303.1°	326-433
Breckinridge, Ky.	Negative		-	-	5.4	-	-	-
Washington, D.C.	2033	2036	64	1.3	0.5	15-40	281.3°	320-358
Belmar, N.J.	Negative		-	-	7.3	-	-	-
Fairbanks, Alaska	2057	2059	29	1.9	0.5	10-20	130.0°	323-362
Oahu, T.H.	Negative		-	-	11.9	-	-	-

[redacted]

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TABLE 5

Acoustic Data for TUMBLER-SNAPPER Shot 4
(Source Time: 01 May, 1630 GMT)

Station	GMT Time of Arrival First Hrs Min	GMT Time of Arrival Max. Hrs Min	Duration (Minutes)	Maximum Amplitude (dynes/cm^2) 0-Peak	Average Noise (dynes/cm^2) 0-Peak	Signal Period (Secs)	Azimuth	Horizontal Phase Velocity (meters/sec)
Ft. Lewis, Wash.	1736	1739	17	9.2	2.0	9-18	151.0°	332-382
Pyote AFB, Tex.	1742	1748	19	8.9	1.5	7-16	301.7°	328-383
Breckinridge, Ky.	1844	1847	32	3.9	1.0	8-18	277.0°	311-434
Washington, D.C.	Negative		-	-	2.2	-	-	-
Belmar, N.J.	Negative		-	-	23.6	-	-	-
Fairbanks, Alaska	1952	1958	34	1.2	0.5	14-20	127.3°	322-390
Oahu, T.H.	Negative		-	-	7.6	-	-	-

[redacted] [redacted]

[redacted]

TABLE 6

Acoustic Data for TUMBLER-SNAPPER Shot 5
(Source Time: 7 May, 1215 GMT)

Station	GMT Time of Arrival First Hrs Min	GMT Time of Arrival Max. Hrs Min	Duration (Minutes)	Maximum Amplitude (dynes/cm^2) 0-Peak	Average Noise (dynes/cm^2) 0-Peak	Signal Period (Secs)	Azimuth	Horizontal Phase Velocity (meters/sec)
Ft. Lewis, Wash.	1319	1323	25	8.0	0.7	5-15	152.8°	290-359
Pyote AFB, Tex.	1327	1335	50	9.3	0.5	5-25	303.0°	317-393
Breckinridge, Ky.	Negative		-	-	1.8	-	-	-
Washington, D.C.	Negative		-	-	6.3	-	-	-
Belmar, N.J.	Negative		-	-	31.4	-	-	-
Fairbanks, Alaska	Negative		-	-	1.2	-	-	-
Oahu, T.H.	1628	1632	9	7.3	4.3	13-30	54.2°	304-362

[redacted]

[redacted]

TABLE 7

Acoustic Data for TUMBLER-SNAPPER Shot 6
(Source Time: 25 May, 1200 GMT)

Station	GMT Time of Arrival First Hrs Min	GMT Time of Arrival Max. Hrs Min	Duration (Minutes)	Maximum Amplitude (dynes/cm^2) 0-Peak	Average Noise (dynes/cm^2) 0-Peak	Signal Period (Secs)	Azimuth	Horizontal Phase Velocity (meters/sec)
Ft. Lewis, Wash.	1305	1308	20	24.8	1.1	9-30	154.9°	330-421
Pyote AFB, Tex.	1320	1323	14	10.0	1.2	8-20	300.8°	325-384
Breckinridge, Ky.	Negative		-	-	4.7	-	-	-
Washington, D.C.	Negative		-	-	1.4	-	-	-
Belmar, N.J.	Negative		-	-	25.7	-	-	-
Fairbanks, Alaska	1528	1529	17	2.0	0.4	12-18	133.6°	325-412
Oahu, T.H.	1601	1605	8	3.3	1.7	8-22	55.8°	343-359

[redacted]

TABLE 8

Acoustic Data for TUMBLER-SNAPPER Shot 7
(Source Time: 01 June, 1155 GMT)

Station	GMT Time of Arrival First Hrs Min	GMT Time of Arrival Max. Hrs Min	Duration (Minutes)	Maximum Amplitude (dynes/cm^2) 0-Peak	Average Noise (dynes/cm^2) 0-Peak	Signal Period (Secs)	Azimuth	Horizontal Phase Velocity (meters/sec)
Ft. Lewis, Wash.	1259	1303	23	27.2	0.6	2-60	157.4°	325-409
Pyote AFB, Tex.	1312	1318	13	12.2	1.2	8-27	299.2°	330-401
Breckinridge, Ky.	Negative		-	-	9.2	-	-	-
Washington, D.C.	Negative		-	-	2.2	-	-	-
Belmar, N.J.	Negative		-	-	2.5	-	-	-
Fairbanks, Alaska	1520	1524	21	1.0	0.5	12-25	130.9°	330-364
Oahu, T.H.	1559	1559	9	2.7	0.9	13-15	56.3°	358-379

[redacted]

TABLE 9

Acoustic Data for TUMBLER-SNAPPER Shot 8
(Source Time: 05 June, 1155 GMT)

Station	GMT Time of Arrival First Hrs Min	GMT Time of Arrival Max. Hrs Min	Duration (Minutes)	Maximum Amplitude (dynes/cm^2) 0-Peak	Average Noise (dynes/cm^2)	Signal Period (Secs)	Azimuth	Horizontal Phase Velocity (meters/sec)
Ft. Lewis, Wash.	1257	1300	28	22.8	0.8	9-22	157.3°	336-384
Pyote AFB, Tex.	1305	1322	51	5.7	0.4	8-23	297.9°	325-387
Breckinridge, Ky.	1429	1432	25	2.3	2.0	10-35	282.0°	301-399
Washington, D.C.	Negative		-	-	3.2	-	-	-
Belmar, N.J.	Negative		-	-	1.9	-	-	-
Fairbanks, Alaska	1516	1516	15	0.6	0.3	10-20	133.0°	335-348
Oahu, T.H.	1555	1555	10	2.8	3.0	20	57.0°	352-384

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6.0 DISCUSSION

6.1 Detection Range

Of prime importance to long-range acoustic detection is the question of how far away the airborne signal can be detected. The detection range depends upon the size of the blast, the atmospheric conditions affecting sound propagation between source and recording station, the noise level existing at the recording station, and the sensitivity of the receiving equipment.

It should be noted that the Nevada Proving Grounds were poorly located insofar as an adequate determination of acoustic detection range was concerned. There was adequate coverage to the east of the test site, poor coverage to the north, only one station at very long distance to the west, and no coverage at all to the south. Coverage to the north could have been greater if it had been possible to use Canadian sites. Security considerations made this inadvisable. Nevertheless, valuable information was obtained even with such sparse coverage. Essential data are contained in Tables 3 through 9.

6.1.1 Shot 1

All results were negative for the first test, 1 April 1952, but the closest station was Washington, D.C., at 3400 kilometers. Noise level at this station was 4.3 dynes per square centimeter. Noise at Belmar, 3585 kilometers, was 6.1; at Fairbanks, 3710 km, 0.6; and at Oahu, 4375 km, 5.8. Lack of detection is probably attributable in part to the low yield of the bomb and in part to noise. Transmission for the spring of year was expected to be practically non-directional.

6.1.2 Shot 2

Signals were detected at approximately 1300 kilometers but not at 2500 km and beyond. Signal amplitudes at 1300 km were very low (6.7 and 11.2 dynes/cm^2, respectively). The limited detection is attributed partly to low source yield and, partly, to noise at the recording stations. Data from Shots 1 and 2 confirm results from JANGLE tests indicating that detection is doubtful at distances of as much as 3400 km for sources of this size.

6.1.3 Shot 3

The spectacular nature of the detection to the east for the 22 April test is not adequately shown in the data from Table 4. Regular AEDS stations picked up the blast at distances greater than 10,000 km. This is believed to be the greatest distance of positive

[redacted]

[redacted]

detection of acoustic waves since Krakatoa and the Great Siberian Meteor. Further details cannot be included because of a security classification higher than that of this report.

The surprising ranges to the east are especially hard to explain in view of the very low amplitudes both at Pyote (1350 km) and at Washington (3400 km). Negative results at Breckinridge (noise 5.4 dynes/cm^2) and at Belmar (noise 7.3 dynes/cm^2) confirm the low signal level at continental stations. The results are attributed mainly to a vagary of propagation in the upper atmosphere (above the known meteorological conditions). Also the unusually high altitude of the explosion (3500 feet above the terrain) may have contributed.

Detection at Fairbanks, 3710 km to the northwest, was the first at that location for continental tests. This is attributed to the very low noise level (0.5 dynes/cm^2) and the spring propagation conditions. Noise at Oahu (11.9 dynes/cm^2) probably precluded detection at that location.

6.1.4 Shot 4

Maximum range of detection was 3710 km (Fairbanks) for the 1 May 1952 test. Signal amplitudes at all stations detecting the blast were very low; therefore, lack of detection at other remote stations is probably explained by station noise levels (2.2 dynes/cm^2 at Washington, 23.6 at Belmar, and 7.6 at Oahu).

6.1.5 Shot 5

The maximum detection range was 4375 km, this time at Oahu to the west. The Signal Corps states that the Oahu "signal was fair; signal to noise ratio was poor except for Channel No. 1; correlation between Channels Nos. 1 and 2 was fair, but with Channels Nos. 3 and 4 it was poor; difficult to determine true amplitudes and periods because of the high noise background." Negative results at Washington and Belmar[1/] might be attributed to noise (6.3 and 31.4 dynes/cm^2, respectively), but Breckinridge also reported negative although the noise was only 1.8. This indicates a possible shift in propagation conditions from a non-directional or slightly eastward preferred direction to a westward preferred direction. Later results confirm this hypothesis.

1/ It should be noted that noise-reducing arrays at Belmar were not of optimum design. This accounts, in part, for the high noise level at this station for all test days.

[redacted]

[redacted] [redacted]

6.1.6 Shots 6 and 7

The 25 May and 1 June 1952 shots were also detected at Oahu (4375 km). Negative results to the east except at the closest station confirm the shift to preferred westward propagation since noise levels at Breckinridge and Washington were low.

6.1.7 Shot 8

Results for the 5 June 1952 shot were similar to those for the 25 May and 1 June shots. A possible signal was detected at Breckinridge (2490 km to the east) but Signal Corps states: "Poor signal; Channels Nos. 3 and 4 especially noisy; detection mainly by means of Channels Nos. 1 and 2; necessary to use envelopes of waveform for computations as individual features do not match." In any case, the signal was quite small. The signal at Oahu must be considered doubtful because of the low signal to noise ratio and the signal at Fairbanks was poor.

6.1.8 Summary

A detection range of at least 3700 km was achieved on all except the first two shots. Shot 1 was not detected at any station, but the closest was at 3400 km. Shot 2 was detected at 1350 km but not at 2490 km. The limited range for these tests is believed due, at least in part, to the low source yield.

A gradual shift in preferred propagation direction is noted with eastward or non-directional propagation in April and early May shifting to westward propagation for most of May and early June. A further discussion of this seasonal change is included in paragraph 6.4.

6.2 Accuracy of Location

In long-range acoustic detection, the question of accuracy of location of the source by remote acoustic measurements is secondary only to the detection range. The two location methods in use are the azimuth-intersection method and the time-difference method. The first requires that the signal be detected by at least two stations and that the azimuth of the incoming wave be determined at each. The source is located by drawing great circle paths along the directions of the azimuths until an intersection is obtained. The second method requires that the signal be detected by at least three stations and that the times of arrival of corresponding points on the wave train be determined at each of the three stations. The location is then established from the time-differences of arrival at the stations if the speed of travel of the acoustic wave is known from previous tests.

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TABLE 10

Azimuth Errors*, TUMBLER-SNAPPER

Station	Shot No.							
	1	2	3	4	5	6	7	8
Ft. Lewis, Wash.	**	0.6°W	1.4°E	1.0°E	1.5°W	2.7°W	5.4°W	5.1°W
Pyote AFB, Tex.	**	2.3°N	2.4°N	1.0°N	2.5°N	0.2°N	1.3°S	2.9°S
Breckinridge, Ky.	**	-	-	0.5°S	-	-	-	4.3°N
Washington, D.C.	-	-	2.3°N	-	-	-	-	-
Belmar, N.J.	-	-	-	-	-	-	-	-
Fairbanks, Alaska	-	-	0.5°E	3.2°E	-	2.9°W	0.4°W	2.5°W
Oahu, T.H.	-	-	-	-	3.1°N	1.6°N	1.0°N	0.1°N

* N means indicated source north of actual source,
E means indicated source east of actual source, etc.

** Not operational.

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6.2.1 Azimuth Errors

The accuracy of location by intersecting azimuth lines is indicated by the error between the true azimuth of the source and the average azimuth of the recorded acoustic wave. Table 10 shows that the maximum error for TUMBLER-SNAPPER was 5.4^{o} and the minimum error was 0.1^{o}. For stations east and west of the source, errors were distributed to the north and to the south of the actual source whereas, for northern stations, errors were east of the source for Shots 2, 3, and 4, and west of the source for Shots 5, 6, 7, and 8. The systematic error for northern sites is believed due to east-west cross-winds and confirms the seasonal shift noted above.

The average absolute value of the error for east-west stations for all shots was 1.8^{o} and the maximum was 4.3^{o}; the average for northern stations for Shots 2, 3, and 4 was 1.3^{o} and the maximum was 3.2^{o}; and for Shots 5, 6, 7, and 8, the average for northern stations was 2.9^{o} and the maximum was 5.4^{o}. These values are consistent with results from BUSTER-JANGLE and GREENHOUSE. Assuming that a correction can eventually be made for the systematic errors caused by east-west cross-winds in winter and summer, an average error of approximately 2.5^{o} can be expected. This would introduce an error in location of roughly 45 km at a distance of 1000 km, 90 km at 2000 km, etcetera. Obviously, the final error of location will depend upon the number and arrangement of stations detecting the signal.

6.2.2 Time Differences

The immediate difficulty with the time-difference method of location is the problem of selecting corresponding points on the acoustic arrivals at three or more stations. Actually, it is practically impossible to pick points corresponding to the same wave front. Thus far, the first detectable signal and the maximum amplitude points have been selected for use in location. Both have obvious disadvantages, but both yield fair accuracy of location under some circumstances. An indication of the errors to be expected is given by the variation in travel speeds presented in Tables 11 and 12.

If only the stations farther than 3000 km from the source are considered, the average speed for first arrivals was 302 meters per second, the minimum was 288 and the maximum was 307. For the same stations, the average travel speed for maximum amplitudes of arrivals was 299 meters per second, the minimum was 284 and the maximum was 307.

No systematic shift in travel speed was noted during the test period for remote stations; however, the Pyote and Breckinridge stations show a tendency toward lower speeds during the

[redacted] [redacted]

TABLE 11

Travel Speeds* for First Acoustic
Arrivals, TUMBLER-SNAPPER

Station	Shot No.							
	1	2	3	4	5	6	7	8
Ft. Lewis, Wash.	**	295	313	313	321	315	324	328
Pyote AFB	**	316	317	313	313	283	290	321
Breckinridge, Ky.	**	-	-	310	-	-	-	270
Washington, D.C.	-	-	310	-	-	-	-	-
Belmar, N.J.	-	-	-	-	-	-	-	-
Fairbanks, Alaska	-	-	300	306	-	298	303	307
Oahu, T.H.	-	-	-	-	288	302	300	304

* All Speeds are in meters per second, great circle distance/travel time.
** Not operational

TABLE 12

Travel Speeds* for Maximum Amplitude
Acoustic Arrivals, TUMBLER-SNAPPER

Station	Shot No.							
	1	2	3	4	5	6	7	8
Ft. Lewis, Wash.	**	243	298	298	303	297	303	313
Pyote AFB	**	305	303	288	279	271	271	260
Breckinridge, Ky.	**	-	-	303	-	-	-	265
Washington, D.C.	-	-	305	-	-	-	-	-
Belmar, N.J.	-	-	-	-	-	-	-	-
Fairbanks, Alaska	-	-	296	298	-	296	297	307
Oahu, T.H.	-	-	-	-	284	298	300	304

* All Speeds are in meters per second, great circle distance/travel time.
** Not operational

[redacted]

[redacted]

latter part of the test period. This is consistent with other seasonal shifts.

For this particular test, it appears that somewhat more consistent results in location would be achieved by using first arrivals rather than maximum amplitude arrivals. This is in contrast to results from BUSTER-JANGLE.

6.3 Signal Characteristics

Signal characteristics are of considerable importance in distinguishing explosion signals from background noise and in establishing something about the nature of the source. Tables 3 through 9 present these signal characteristics.

6.3.1 Amplitude

The maximum amplitudes of all signals for TUMBLER-SNAPPER ranged from 30 to 0.6 dynes per square centimeter. As for previous tests, amplitudes were greatest for the closest stations and tended toward smaller values at the more distant locations. The average maximum amplitude at distances greater than 3000 km from the source was 2.4 dynes per square centimeter, the minimum was 0.6, the maximum 7.3.

Amplitudes at eastern stations were much smaller than those recorded for BUSTER-JANGLE for tests of equivalent yield. Further, amplitudes at Pyote were not too much different from those at Ft. Lewis during Shots 2, 3, 4, and 5, but Ft. Lewis amplitudes were at least a factor of two greater than those at Pyote for Shots 6, 7, and 8. This contrasts with the BUSTER-JANGLE data which showed Pyote amplitudes very much larger than those at Ft. Lewis for every shot. These data provide additional evidence of the seasonal shift in propagation.

6.3.2 Duration

The average persistence of detectable signal was 23 minutes. The minimum duration was 6 minutes and the maximum was 64 minutes.

6.3.3 Frequency

Significant signal periods established by visual analysis ranged from 2 to 40 seconds.

Harmonic analyses of sections of the Fairbanks record for Shot 3, 22 April, and the Oahu record for Shot 6, 25 May, were made by the Signal Corps using a Mader-Ott mechanical-type

analyzer giving direct measurement of sine and cosine components down to the thirty-third harmonic. A fundamental of 192 seconds was used in both cases. Components in the Fairbanks record believed due to the signal ranged from a period of 3 seconds to 70 seconds, with the peak at 24 seconds. Roughly the same range in signal periods was observed in the Oahu record, the peak being at 16 seconds.

Spectrum analysis by the National Bureau of Standards using the magnetic tape recording at Washington for Shot 3, presented in Figure 3, showed maximum power in the 10- to 20-second band. The 5- to 10-second band also gave considerable power. Levels for periods longer than 20 or shorter than 5 seconds were negligible compared to those for the other bands. In contrast to similar power-level records for Ft. Lewis during BUSTER-JANGLE, the Washington analysis showed a gradual increase in level to its maximum value whereas the BUSTER-JANGLE analysis showed an abrupt increase to the maximum value.

6.3.4 Horizontal Phase Velocity

Values for horizontal phase velocity, the velocity with which an acoustic wave moves across a horizontal array of detectors, ranged from 290 to 434 meters per second. On several occasions, velocities less than the normal speed of sound at ground level were observed. These values are not possible according to ray-tracing theory for sound propagation and are believed due to diffraction phenomena. Similar observations have been reported for SANDSTONE, GREENHOUSE, and BUSTER-JANGLE.

6.4 Seasonal Effects

The results presented above, when combined with results from GREENHOUSE and from BUSTER-JANGLE, confirm a seasonal pattern in acoustic propagation through the upper levels of the atmosphere. The pattern seems to be: (a) preferred eastward propagation in the winter (roughly October through March), (b) preferred westward propagation in summer (roughly May through August), (c) non-directional or mildly directional propagation in spring and fall. TUMBLER-SNAPPER illustrates the changeover from spring to summer propagation. During the early shots (2, 3, and 4) detection ranges were variable with some indication of eastward preference, azimuth errors indicated light, variable westerly cross-winds, travel speeds were about the same in all directions, and amplitudes were low compared to BUSTER-JANGLE. Starting with Shot 5 and becoming more apparent for Shots 6, 7, and 8, detection ranges indicated westward preference and azimuth errors all showed effects of easterly cross-winds. Travel speeds remained about the same and amplitudes were less for eastern stations compared to northwestern stations at equivalent distances. All of these results point to a shift in stratosphere winds to easterlies early in May.

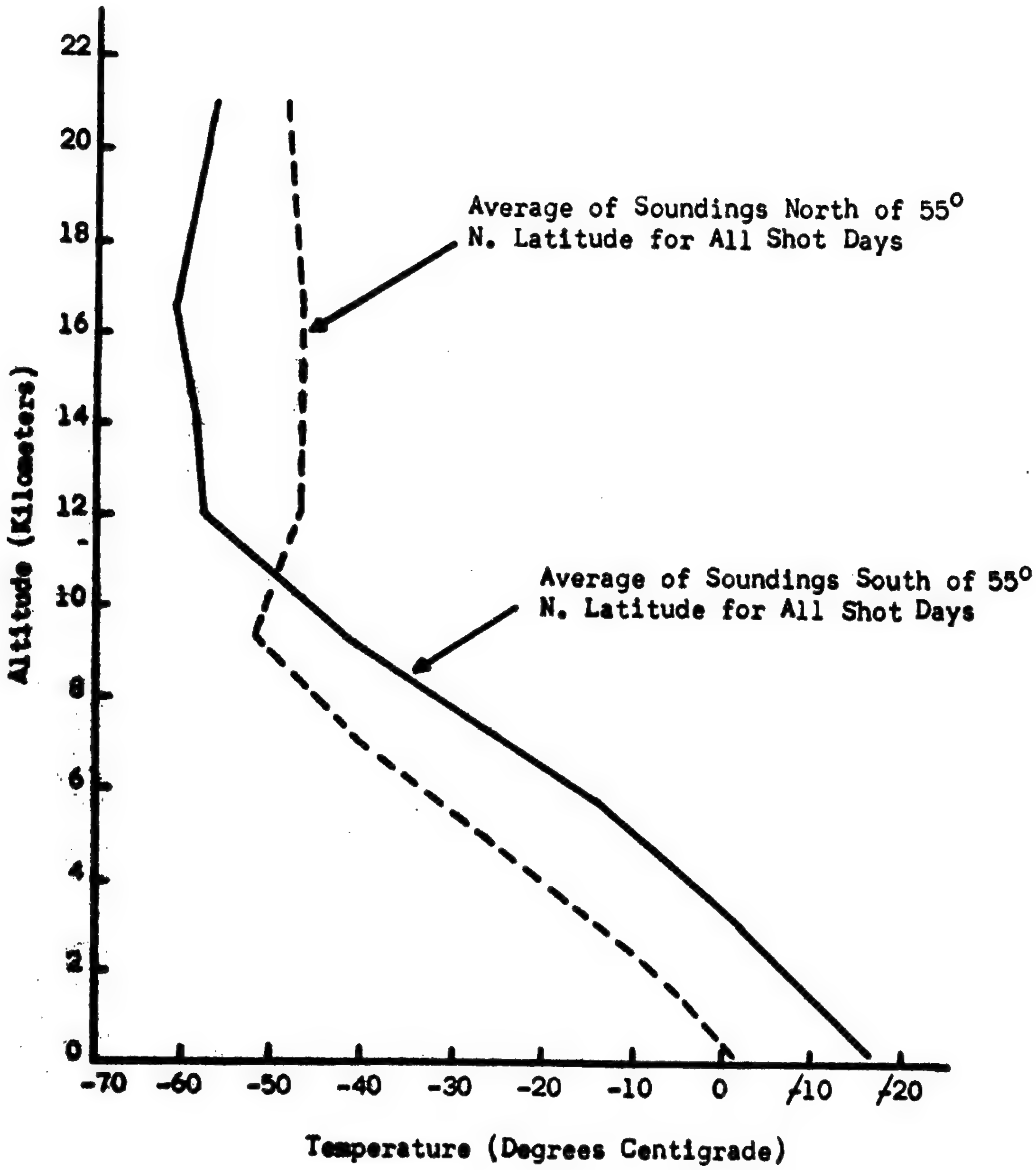

Fig. 4 Temperature Structure in the Upper-Atmosphere During TUMBLER-SNAPPER (1 April - 5 June 1952)

[redacted]

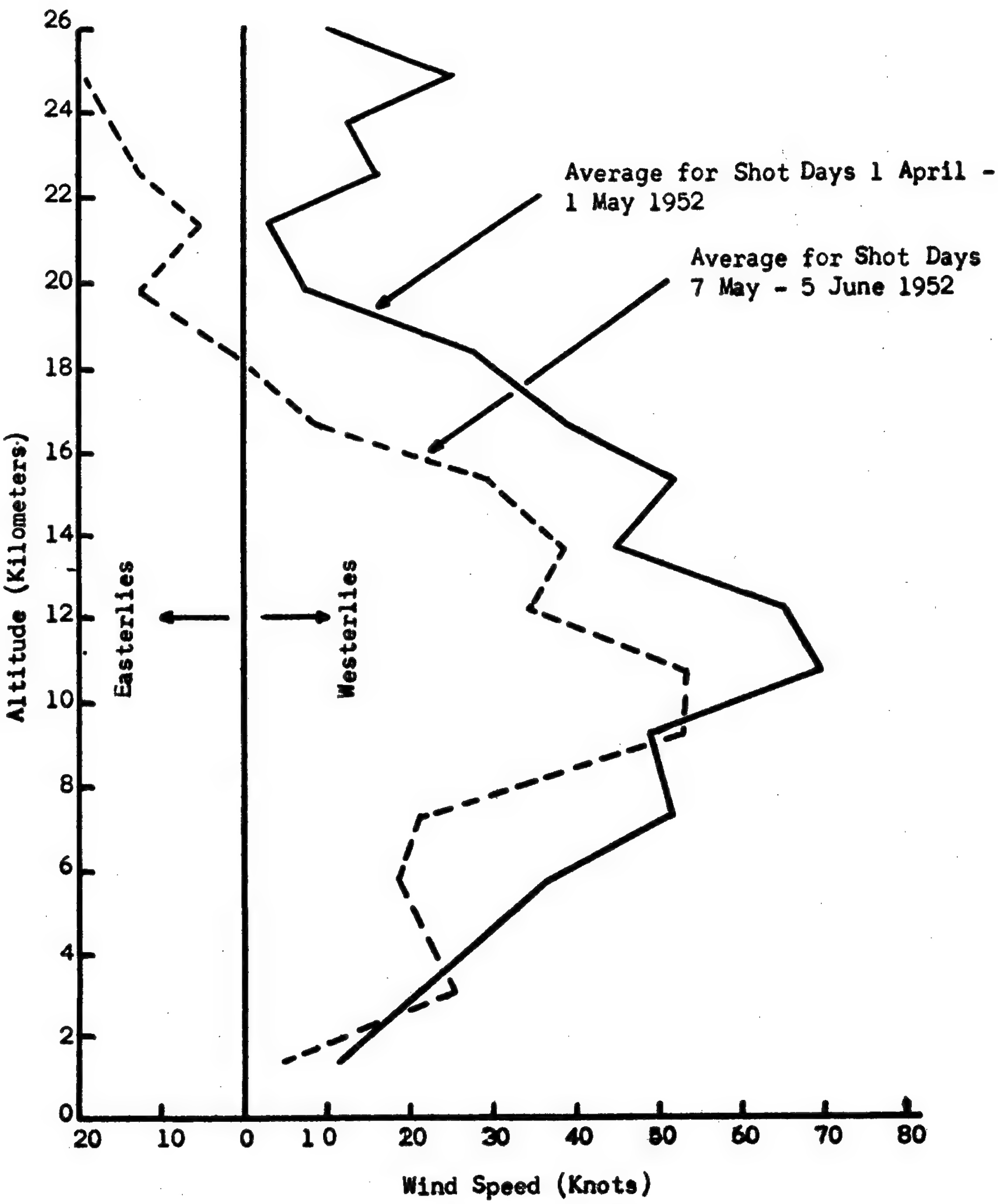

Fig. 5 East-West Wind Components in the Upper-Atmosphere During TUMBLER-SNAPPER (1 April - 5 June 1952)

[redacted]

An attempt was made to obtain meteorological evidence to support the apparent shift in upper-level winds indicated by the acoustic data during the test series. Vertical atmospheric cross-sections showing winds and temperatures on shot days were constructed by the Special Projects Section of the U.S. Weather Bureau for great circle paths to the west, northwest, and east of the Nevada Proving Grounds. Examination of this bulk of data gave the following significant results:

a. The temperature structure, insofar as acoustic propagation is concerned, remained stable during the test period. There were minor differences from one shot day to the next and variations between stations, but the only marked difference noted was that northern stations (Alaska) showed a lower tropopause (about 10 kilometers) and a higher minimum temperature (-50°C) compared with stations at the latitude of the test site (tropopause at 12 km and minimum temperature about -65°C). Figure 4 shows the average temperature vs. altitude structure at locations below 55° north latitude and at locations above 55° north latitude. The curves were obtained by averaging all pertinent temperature soundings at a given altitude on all shot days.

b. Figure 5, presenting average east-west wind components for the first four shot days and for the last four shot days, shows the shift in direction of upper-level winds from light westerlies during April to light easterlies during May and early June. This appeared to be consistent at altitudes above 20 kilometers for all soundings, including the northern stations. While there were no data available at altitudes from 30 to 60 kilometers where winds affect sound transmission most, the shift in wind direction at the 20 kilometer level is believed indicative of a more marked shift in the same direction at higher altitudes and is consistent with the shift in direction predicted from the sound data.

7.0 CONCLUSIONS

7.1 Detection Range

It is concluded that the distance at which the airborne acoustic waves from atomic explosions can be detected is dependent on the season. Minimum detection ranges occur, generally, in spring and fall when acoustic energy is spread in all directions from the source. Maximum ranges are expected in winter and summer when stratosphere winds channel greater amounts of acoustic energy in one general direction. Notable exceptions such as the extreme eastward detection for the 22 April 1952 test occur and their causes are not always obvious. In most cases, deviations from the seasonal effect on detection range can be explained by noise levels at the recording

stations but some cases can apparently be attributed only to transmission peculiarities.

It is further concluded that the chances of detecting an atomic blast of the size of the JANGLE shots and the first two TUMBLER-SNAPPER shots at distances greater than 3000 km are only fair. Chances of detecting explosions the size of other TUMBLER-SNAPPER shots at ranges of 3500 to 4500 km are good.

7.2 Accuracy of Location

Present evidence indicates that an average error in location of an unknown source by remote acoustic measurements of 50 kilometers at a range of 1000 kilometers (250 km at 5000 km) can be expected providing that sufficient test data are available so that a correction for east-west wind effects can be made. Both the azimuth-intersection and the time-difference methods of location are useful.

7.3 Equipment Characteristics

The signal characteristics for TUMBLER-SNAPPER, like BUSTER-JANGLE, indicate that the pass-band characteristics of present equipment are good for the ranges of yields represented by these shots. However, the overall trend to lower frequencies as the source size increases may eventually require an extension of the low-frequency response of the equipment.

The limited range of detection for small shots points out the need of further study of methods to improve signal recognition capabilities. Further increase in equipment sensitivity will undoubtedly be required if the goal of operating at maximum detection effectiveness is to be achieved and maintained.

7.4 Signal Characteristics

Data from TUMBLER-SNAPPER support the results from GREENHOUSE and from BUSTER-JANGLE regarding the limited spread in horizontal phase velocities measured for atom bomb signals. Indications are that incoming acoustic waves arrive with elevation angles within 40° of horizontal. The upper limit to these velocities (approximately 450 meters per second) affords an excellent tool in eliminating spurious signals due to seismic disturbances and other disturbances of unknown origin.

The general trends in signal frequency and signal amplitude with source size, while not capable of indicating relative yields even to an order of magnitude, are important in sorting out spurious signals due to gunfire, small TNT explosions, et cetera.

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The fact that detectable signals from A-bombs ordinarily persist for several minutes is also useful in interpreting signals from unknown sources. In addition, this characteristic is useful in eliminating random correlations of single noise pulses. Duration is not used as absolute proof of signal significance because it is possible that noise might obscure all of a significant signal except the maximum amplitude pulse. However, as a practical matter, only one such instance has been observed in the large number of recordings made during GREENHOUSE, BUSTER-JANGLE, and TUMBLER-SNAPPER.

7.5 Seasonal Effects

Results of TUMBLER-SNAPPER illustrate the change in sound propagation occurring in the spring and early summer. Acoustic data from all atomic tests and from small explosion tests by the Navy Electronics Laboratory[1] in the California-Arizona Desert point to a seasonal shift in east-west winds in the stratosphere. These results agree with meteorological observations although the meteorological soundings do not extend to sufficiently high altitudes to constitute an adequate check on the sound data. East-west winds cause systematic azimuth errors for north and south acoustic detection stations and systematic shifts in travel speed for east-west sound propagation.

8.0 RECOMMENDATIONS

Continued remote acoustic measurements during future atomic tests are recommended in order to establish the limits of detection capabilities of present equipment and to determine the direction to be taken in the improvements of equipment and techniques. Particular emphasis should be placed on measurements during summer and fall test periods and during tests having unusual test conditions.

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[1] U.S. NEL Final Report on AFOAT-1 Project Authorization B/10/A/ONR/NEL "Experimental Study of Acoustic Waves Propagated in the Atmosphere from Small Explosions," by Johnson, Hale, and Focke, dated 30 Sept. 1951 (CONFIDENTIAL - SECURITY INFORMATION)

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